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WITNESS my hand this Twentieth
day of May 1999

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AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

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A.C.N. 060 658 764

Invention Title:

COMPACT CONFOCAL ENDOSCOPE AND ENDOMICROSCOPE METHOD AND APPARATUS

The invention is described in the following statement:

COMPACT CONFOCAL ENDOSCOPE AND ENDOMICROSCOPE METHOD AND APPARATUS

The present invention relates to compact confocal endoscopes and microscopes (including endomicroscopes), of particular but by no means exclusive application in the internal examination of the human body.

Existing confocal endoscopes employ beam splitting apparatus comprising partially mirrored surfaces or compound prisms. Such apparatus are both relatively bulky and designed to function efficiently only when the two exit beams diverge at a relatively high angle (which is often approximately 90°). Conventional beamsplitters are generally 45° cubes or pellicles or are near orthogonal to the optic axis (as in the F900e) to eliminate polarisation state noise.

These configurations, however, render a beam splitting head bulky, as suitable photoreceptors or light conduits must be located almost perpendicular to the light source and/or incident light beam. The resulting beam splitter may not, therefore, be deployed in particularly narrow apertures or other sites with restricted access, and nor may it be located on an endoscope head. To do so would increase the space required around the endoscope head, limiting the range of locations in which the endoscope could be deployed. Further, this would increase the mass of such an endoscope head, rendering it unwieldy for some applications. Additionally, beam splitters of this type - with such highly divergent outgoing beams - cannot be readily used where the photo emitter (be it a laser, optical fibre or otherwise) is to be moved in order to scan the sample. Clearly the light receiving means (which may be a pinhole, optical fibre or some form of photo-detector) must be moved in such applications in synchrony with the photo emitter. However, accurately maintaining such

registration where existing beam splitters are employed is impractical, owing to the separation of source and exit beams (and hence or emitter and receiving means).

It is an object of the present invention, therefore, to provide a confocal endoscope beam splitting method and apparatus that at least partially overcomes one or more of the above disadvantages of existing devices.

Accordingly, the present invention provides a confocal endoscope or microscope including:

a light source of coherent light for illuminating a sample;

a beam splitter; and

light receiving means, wherein an incident beam of light from said light source is directed onto said beam splitter and hence onto said sample, and light returning from said sample and incident on said beam splitter is deviated or displaced by said beam splitter by a small angle or distance relative to said incident beam, and received by said light receiving means located to receive said returning light and near said light source.

The beam splitter may be provided by any suitable means. It should be noted that the light returning from the sample may include both fluorescent and reflected light; some beam splitters are envisaged (as will be detailed below) that will provide suitable deviation of the fluorescent light, while others are envisaged that will provide suitable deviation of the reflected light, or of both fluorescent and reflected light. It should also be noted that references to an "endoscope or microscope" should be understood to include reference to an endomicroscope.

Preferably the apparatus includes an optical head and said light source is located in or on said head.

Preferably said endoscope or microscope includes heating means for maintaining said head at a temperature substantially equal to that of said sample.

This temperature will, for human samples *in vivo*, human body temperature. This is desirable for patient comfort as well as for the stability of operation of the head components.

Preferably said light source and said light receiving means are on a single mounting means.

Preferably said mounting means is moveable for scanning said light source.

Preferably said mounting means includes a reed, and more preferably said mounting means is an electromagnetically vibrated reed.

Preferably said light source and said light receiving means are adjacent or touching.

Preferably said light source is an optical fibre tip.

Alternatively said light source is a laser, and more preferably a blue light laser.

Preferably said beam splitter includes a plurality of prisms.

Preferably said plurality of prisms provide minimal net deviation or translation, so that said coherent light or light reflected from said sample emerges from said plurality of prisms substantially parallel to and optically coaxial with its path immediately before impinging said plurality of prisms.

Thus, the plurality of prisms acts as a "direct vision" spectroscope.

Preferably said plurality of prisms is arranged to focus confocal return stokes fluorescence to form a line, said line forming a spectrum in which shorter wavelength fluorescence is located towards a first end of said line closer to said light source, while longer wavelength fluorescence is located towards a second end further from said light source.

Preferably said apparatus further includes means to allow light on either side of a spectral line in said returning light to be included with light from said spectral line when said returning light impinges on said light receiving means.

Preferably said means is controlled by a mechanism which occludes light which is more distant in wavelength than a desired amount from said spectral line, to allow control of depth of field isolation.

Preferably the apparatus includes optical elements to divert chosen wavelength portions of said spectral line (and optionally light close in wavelength to said spectral line) to one or more photodetectors to give different spectral channels for imaging.

Preferably the apparatus includes at least one optical waveguide channel to convey said returning light to said photodetectors.

Preferably the apparatus includes a laser and an optical waveguide to convey light from said laser to said light source.

Preferably the apparatus includes a first optic waveguide

to convey light to said specimen and at least one second optic waveguide channel to convey said returning light to said photodetectors, and said beam splitter is disposed in said head between said first and second optic waveguides.

Alternatively the apparatus includes a return fibre and said beam splitter is located between a light exit area of said return fibre and said photodetectors, to provide spectral separation after said returning light exits said fibre.

Preferably the apparatus includes an aperture slit moveable in front of said photodetectors simultaneously with said scanning to compensate for changes in beam splitter deviation.

Preferably said lenses include at least one apochromatic lens.

Preferably said prisms include an SF 11 or SF 59 prism.

Such a combination is reasonably achromatic and non-deviating for the 515 nm - 650 nm range, and which has substantial dispersion for the blue.

According to the present invention there is also provided a method for performing confocal endoscopy or microscopy including:

illuminating a sample by means of an incident or excitatory beam of coherent light; and

deviating or displacing light returning from said sample by a small angle or distance relative to said incident beam.

Preferably said method includes receiving or detecting said returning light at a point close to a source of said incident or excitatory beam.

Preferably said deviating or displacing of said light

returning from said sample is effected by means of a beam splitter.

The present invention also provides a confocal endoscope or microscope including:

a light source of coherent light for illuminating a sample;

a beam splitter; and

light receiving means, wherein an incident beam of light from said light source is directed onto said beam splitter and hence onto said sample, and light returning from said sample and incident on said beam splitter is deviated by said beam splitter by a small angle relative to said incident beam, and received by said light receiving means located to receive said returning light and near said light source, and said beam splitter includes polarisation rotating means and deviation means to separate light of different polarisations, and operates by optically rotating said coherent light and said returning light.

Preferably the polarisation rotating means is based on optical rotary dispersion and includes a chiral medium to optically rotate said coherent light and said returning light.

Alternatively the polarisation rotation means includes a Faraday effect material, said material having simultaneously magnetic lines of force in the same direction as the propagation direction of said light, whereby the E vector of said coherent light is rotated as it passes through said material .

Alternatively the polarisation rotation means includes phase plates or retardation elements, of a material whose structure is anisotropic at a molecular or crystalline level.

Alternatively the polarisation rotation means includes liquid crystals.

Preferably said liquid crystals are optically active and/or birefringent.

Preferably said liquid crystals are cholesteric liquid crystals.

In one preferred embodiment said optical rotation is provided by intrinsic polarisation properties of the sample or of any intermediate optical medium.

Thus, as many biological materials exhibit birefringent properties and or produce optical rotation, it is possible to use this property in the present apparatus.

The invention also provides a method for maintaining registration in a confocal endoscope or microscope including a light source and a light receiving means, including:

splitting light returned from a sample with a small angle deviation beam splitter;

employing said light source and said light receiving means located on a single moveable mounting means;

moving said mounting means to scan said light source and thereby said sample.

Preferably said beam splitter includes a plurality of prisms.

Preferably said plurality of prisms provide minimal net deviation.

Preferably said moving of said mounting means comprises vibrating said mounting means.

Preferably said mounting means is a reed.

Preferably said mounting means is an electromagnetically vibrated reed.

In order that the present invention may be more clearly ascertained, preferred embodiments will now be described, by way of example, with reference to the accompanying drawing in which:

Figure 1 is a schematic view of a confocal endoscope according to a preferred embodiment of the present invention;

Figure 2 is a schematic view of the optical configuration of an endoscope head according to another preferred embodiment of the present invention;

Figure 3 is a schematic view of the optical configuration of an endoscope head according to another preferred embodiment of the present invention;

Figure 4 is a schematic view of the optical configuration of an endoscope head according to another preferred embodiment of the present invention;

Figure 5 is a ray trace of the prism combination of figure 4;

Figure 6 is a schematic view of the optical configuration of an endoscope head according to another preferred embodiment of the present invention;

Figure 7 is a schematic view of the optical configuration of beamsplitter of an endoscope head according to another preferred embodiment of the present invention;

Figure 8 is a schematic view of the optical configuration of an endoscope head according to another preferred embodiment of the present invention; and

Figure 9 is a schematic view of the Faraday effect optical rotator of an endoscope head according to another preferred embodiment of the present invention.

A confocal endoscope according to a preferred embodiment of the present invention is illustrated schematically at 10 in figure 1. The Endoscope 10 includes a miniature laser diode 12, a scanning mechanism 14, an astigmatism corrector 16, a lens 18 and a Nomarski type polarisation separation prism, often referred to as a Spatial Walkoff Filter (SWF) 20.

A laser beam is generated by the laser diode 12, which is mounted on the scanning mechanism 14. The divergent laser beam passes through the astigmatism corrector 16 to lens 18 which roughly collimates the beam. The collimated beam 34 then passes through the SWF 20.

The polarisation axis of the beam is aligned to the SWF 20 so that there is no separation of orthogonal polarisation vectors of the laser beam, and the beam then passes through a pair of Kerr cells 22 and 24 to lens 26, which focusses the beam to a Gaussian waist 30 within a specimen 28.

Return light, either fluorescence or reflection from the entire interaction volume (a diabolo shaped volume) within the specimen, returns through lens 26. However only light from the Gaussian waist 30 will exclusively retrace the full set of incoming ray paths through the optical system back to the SWF 20.

For imaging in reflection, a current is passed through coil 32 surrounding Kerr cell 22 so that the combined effect on Kerr Cell 22 and Kerr Cell 24 is to rotate the E vector of the polarised return light by 90° degrees relative to the outgoing light. Hence, when the return beam traverses SWF 20 it is diverged from the outgoing beam path 34 and instead it travels along beam path 36.

This returning beam is converged by lens 18 to a focus 38

which causes it to enter the core at the tip of an optic fibre 40.

The return light is carried in the core of fibre 40 to the opposite end 42, from which it is emitted and passes to photomultiplier tube (PMT) 44. The electrical output of PMT 44 in conjunction with the XY positional information from the scanning mechanism 14 is used to build up a 2D data set forming the image.

In fluorescence imaging mode the current in coil 32 is adjusted along path 36.

The materials of Kerr Cell 22 and Kerr Cell 24 are different and may be chosen so that the difference in optical rotation for the two together rotates the anticipated range of fluorescent wavelengths by about the same angle on traversal whereas the rotation of the reflected excitation light is rotated by a substantially different amount.

Alternatively it may be chosen so that the rotation angle is wavelength independent. In these latter cases separation between fluorescent wavelengths (and reflection) is achieved by means of lens 46 and prism 48, and separate channels of acquisition are obtained from separate photodetectors 44 and 50.

Figure 2 is a schematic view of the optical configuration of an endoscope head 52 according to a further preferred embodiment of the present invention. The head 52 includes first lens 54 for collimating blue laser excitatory beam 56. Collimated beam 58 passes through prism 60, and is then focussed to a Gaussian waist 62 (in use, within a sample) by second lens 64.

Return light will retrace the incoming light back to prism

60, but will be refracted through a different angle owing to its different wavelength; hence prism 60 will act as a beam splitter, and the return light 64 will emerge from first lens 54 separated from incoming beam 56.

The head 52 of figure 2 is very simple, but the angular deflection at the prism and hence non-linear optic axis may - in some applications - be disadvantageous, as it imposes a shape for the head which may be inconvenient to use or make it difficult or impossible for the head to pass through a narrow tube.

An optical configuration of an endoscope head according to a further preferred embodiment of the present invention is shown in schematic form in figure 3 at 66. The head 66 includes a prism combination 68 (to give a straight through optic axis and a straight cylindrical head for the endo- or endomicroscope design) as well as first and second lenses 70 and 72. Again, return light 74 emerges from first lens 70 separated from incoming excitatory beam 76.

Prism combination 68 utilises the same principle as an achromatic doublet except that the angles are reversed to give minimum deviation but maximum dispersion.

An optical configuration according to a further preferred embodiment of the present invention is shown in schematic form in figure 4 at 78. The head 78 includes a direct vision spectroscope three prism combination 80 and is comparable (though in reverse) to a Hastings achromatic triplet, to reduce or eliminate astigmatism resulting from the arrangement of figure 3. Prism combination 80 includes a 60° SF11 Flintglass central prism 82 cemented between two 45° BK7 prisms 84 and 86. This arrangement gives almost 0° deviation for the blue laser line and considerable overall dispersion, between incoming excitatory beam 88 and return beam 90.

Figure 5 is a ray trace for the prism combination 80 or figure 4, showing central 60° SF11 Flintglass prism 82 between the pair of 45° BK7 prisms 84 and 86. Incoming beam 92 will be dispersed into an undeviated component 94, with the red deviated as shown at 96 and blue at 98. The total dispersion of this particular combination 80 is greater than would be required for a miniature endomicroscope head and prisms of much smaller angles (and shorter overall dimensions) may be suitable and, in some applications, preferable.

Figure 6 is a schematic representation of an optical configuration 100 for an endoscope head according to a further preferred embodiment of the present invention. The configuration 100 includes a combination of plano-concave and plano-convex lenses 102 and 104, optically coupled together to give a system in which the divergence of the return beam 106 relative to the incoming excitatory beam 108 can be almost infinitely varied, but altering the position of plano-convex lens 104 within the concavity of plano-concave lens 102. This configuration 100 also includes collimating lens 110, focussing lens 112 and prism pair 114 located between plano-convex lens 104 and focussing lens 112.

The embodiments of figures 2, 3, 4 and 6 have the advantage of simplicity but suffer from the drawback that the return light fluorescence, even from a single pure fluorophore, consists of a broad range of wavelengths, which does not focus to a spot but spreads into a spectral line. This makes collection by the return fibre more difficult (a line of fibre cores or a fibre bundle is required or special fibre design with elongated collection aperture means) and also reduces the isolation of the focal plane to an equivalent value for a slit scanning confocal system.

There is a way of getting around this using a prism based system in the head. The common optical glasses including the Flint glass Crown glass pair SF11 and BK7 referred to earlier are made from glass types which fall on Abbe's 'normal' glass line. On this line the partial dispersions of the glasses match in a way which allows doublet lenses to be constructed which are achromatic for the visible region 400-700 nm (a likely requirement of lenses for human use). Any pair of glasses from this line can be combined in a concave convex doublet (suitably matched) to produce an achromatic lens combination.

There are glass types available which do not follow the Abbe's 'normal' glass line, that is their partial dispersions do not match and they are said to have deviating partial dispersions (see Schott Tables). These glasses are formulated to correct the slight secondary spectrum (green-orange) which remains in achromatic doublets because the partial dispersions even of the normal line glasses never exactly match for all wavelengths. In a lens design the addition of an appropriately figured third lens of such a glass type allows the spectral curves to match at three levels and thus greatly reduces the secondary spectrum. Such lenses are known as 'apochromatic'. Apochromatic lenses have many more individual lens elements in them (up to 20 in some cases) to correct for other aberrations.

After an appraisal of the spectral deviation curves, one can choose such a glass to replace the BK7 crown prism, and combine this replacement with an SF 11 or SF 59 prism to produce a combination which is reasonably achromatic and non-deviating for the 515-650 nm range but which has substantial dispersion for the blue.

Such a prism pair will produce a good separation between the blue 488nm excitation line and the fluorescence. The

fluorescence spectrum is effectively bunched up although the graph is not entirely level but folds back (the angular deviation will actually only be exactly the same for matching pairs of wavelengths). However, this is a considerable improvement. A third glass type taken from another line on the Abbe deviation glass curve will produce even further flattening, and sets of three wavelengths will have exactly matchings angular deviations.

A fourth prism of suitably chosen glass could be added to further correct the spectrum to four wavelengths as shown in figure 7 (which comprises a direct vision prism pair 116 comprising four prisms 118a,b,c,d).

Such a combination of prisms could be made from standard Schott catalogue optical glasses. Fortunately it is much easier to find standard glass types which have appropriate RI deviation in the blue than the red, but the number of prisms required could be reduced and the design made more compact by the choice of special optical materials. Such materials could include fluorite (CaF_2) or magnesium fluoride in combination with a second optical material that exhibits strong anomalous dispersion.

It is also possible to design an optical material for the second prism with a more strongly kinked anomalous deviation curve, which would minimise the number of prisms (possibly to just two) and their angle and hence the optical thickness. The specifications would be that the material is glassy or isotropic (cubic crystal structure), that it has an intrinsic absorbance or a dopant which absorbs in the indigo/violet part of the spectrum, shorter than 488nm, so that the positive asymptotic limb of the anonalous dispersion curve lifts the deflection angle from the 488nm but has the dispersion uniform and of much lower gradient for the 515-650nm region.

The optical medium or dopant must not fluoresce or have too high an absorption at the excitation wavelength and should be free of absorption lines in the 515-650 nm fluorescence region. Suitable materials include certain organic dyes dissolved in transparent polymer or might potentially be formulated from a rare earth doped fluorozirconate ZBLAN glass.

This principle of successive corrections by a train of optical elements and the use of 'kinks' in the active parameter graphs (the relevant equivalent to anomalous dispersion in other optical properties) can be applied to a number of other novel beamsplitter methods and appartuses according to the present invention.

For example, figure 8 is a schematic view of an endoscope head 120 with a beamsplitter 122 based on optical rotary dispersion in a chiral medium. This beamsplitter depends on the optical rotatory dispersion of a medium containing chiral molecules or chirally oriented bonds, such as glucose or $NaClO_3$.

The explanation which follows is couched for an embodiment in which a liquid is used as the optically active medium although in practice this may require an excessive path length and a chiral crystal (such as quartz), cut with faces orthogonal to the C axis, may be prefered, as optically active (chiral) crystalline materials have a far greater rotating power than most liquids; quartz, for example, has a rotating power of 21.7° per mm whereas dextrose syrup has a rotating power of 1° per mm.

The operation of this method requires the light to be polarised in a fixed vector state as from a laser diode and hence polarisation maintaining fibre is needed if the design is adapted to a two fibre system.

The polarised light 124 emitted from a laser diode (not shown) is collimated by lens 126 and passes through a prism pair in the form of SWF 128. The SWF 128 is oriented so that the eigen-vector of the light is parallel to the prism's fast (or slow) axis. This differs from Nomarski microscopy in which the polarisation vector is oriented at 45° to the fast and slow axes of prism and the beam is split 50:50. Thus, in this embodiment the light is not split into separate orthogonal polarisation beams on its first traversal of the SWF 128.

The beam next passes into a tube or column 130 of dextrose syrup (d glucose), which rotates the plane of the polarisation vector in a right handed spiral by a certain amount, preferably > π radians. The light beam exits the flat face 132 of the far side of the tube 130 and passes to an objective lens 134, which focuses the beam to a Gaussian waist 136 within the specimen (not shown).

Fluorescence generated at the Gaussian waist 136 is Stokes shifted but is in general predominantly of the same polarisation vector state as the polarisation vector of the excitation beam (as long as the relaxation time of the excited state of the fluorophore is not too long).

Some of this light and some of the excitation wavelength reflected from the region passes back through the objective lens 134 to the dextrose column 130. Reflection from most materials does not alter the polarisation vector.

In traversing the column 130 in the reverse direction the polarisation vector is again rotated in a right handed spiral, rotating backwards by exactly the same angle by which it was rotated forwards on its first pass. The fluorescent light is also rotated in a right handed spiral direction but, because of optical rotatory dispersion (that is, as the interaction strength between the spiral

mechanical oscillators is wavelength dependent), it is rotated through a different angle to the reflected beam.

For the most efficient operation of the beamsplitter 122, the difference between the optical rotatory dispersion angles of the reflected light and the fluorescence should be $\pi/2$.

After traversing the chiral medium in column 130, the light then passes back to the prism pair 128. In this embodiment, prism 128a is made of a birefringent material such as calcite, cut and polished at a suitably oriented crystal angle. The reflected return light acts as the 'ordinary' ray and is refracted by the prism 128a along exactly its initial path to its point of origin. The fluorescent return light - having its polarisation vector at $\pi/2$ relative to the reflected ray - acts as the 'extraordinary' ray and is deflected by a different angle when it passes the prism 128a. This prism 128a also introduces a slight chromatic dispersion as well because the fluorescence consists of a range of wavelengths. This dispersion of the fluorescence is compensated for by the matching dispersion of the second prism 128b (the next element traversed by the returning light). The light is then focussed by the lens 126 and the confocal return enters the core of the return fibre 138 and is transmitted along the fibre to a photodetector (not shown).

Note: where referred to below, the SWF is employed in a similar fashion in the following apparatuses and the description here will cover these systems as well.

This principle can operate for Argon Krypton lasers with two or more laser excitation wavelengths simultaneously traversing the dextrose column. Each wavelength will be rotated on its first traversal and after reflection, its rotation exactly reverse spiralled on return to the

original source. The fluorescence from each excitation wavelength will be rotated by a different angle on return and therefore a portion of the fluorescence from each excitation wavelength be deflected at the extraordinary angle at the birefringent prism so as to enter the second fibre.

As another improved embodiment it is possible to choose a second optically active medium in the opposite enantiomorphic form which had an optical rotating dispersion curve which matched dextrose for the green, yellow and orange wavelengths but which kinks markedly for the blue, and to combine this to produce an 'achromatisation' of the fluorescence but a separation of the excitation wavelength. For example, laevulose (the laevo enantiomorphic form of glucose) produces a left handed rotation of the plane of the polarisation vector of light passing through it. This opposes the rotation of the dextrose and, where the optical rotating dispersion curve of laevulose had a different gradient compared to dextrose (analogous to the refraction dispersion curves of the flint glass prism of the previous design), it is suitable for this purpose. Laevulose does not have the required kink in the graph for blue, but other substances do.

Quartz is a uniaxial crystal type and this may result in problems for certain scanning embodiments. For example if the scanning is carried out by means of a rastered movement of the blue laser chip or of the fibre tip then the beam will, for much of the time, propagate through the quartz crystal plate at a slight angle to the C axis. This will introduce birefringence into the optical path and consequent eigenvector separation which will add extra complexity and reduce optical efficiency. There are optical materials (such as sodium chlorate crystals) which are optically active, but not birefringent which would avoid this difficulty. The rotary power of this material

is 3.1° per mm (for the sodium yellow lines) which is rather low for some applications. Materials with much higher optical rotatory power are detailed below.

In another preferred embodiment of the present invention, the Faraday effect is used to provide the desired beamsplitting (that is, the rotation of the E vector of linearly polarised light as it passes through a material which simultaneously has magnetic lines of force in the same direction as the propagation direction of the light). The optical rotator of a beamsplitter according to this embodiment is shown at 142 in figure 9. The optical rotator 142 includes a cylindrical piece of glass 144 (chosen to have a high Verdet constant) with flat polished AR coated ends 144a surrounded by a tubular cylindrical magnet 146 with north face N and south face S. The beamsplitter (like those described below) is otherwise like beamsplitter 122 of figure 8 with a birefringent prism acting as the beam separation element (but with the optical rotator replacing the column 130). As the beams of light traverses the optical rotator, the magnetic field of magnet 146 progressively rotates the E vector. Faraday rotation differs from chiral optical activity in that the reflected light undergoes further rotation of the E vector in the same direction when retraversing the glass 144. This is a non-reciprocal effect unlike chiral rotation in which the spiral retraces its original path on reflection.

This difference is important because it means that the beamsplitter can be tuned to obtain maximum rotational efficiency of the reflected beam, that is 45° E vector rotation from each traversal, thus minimizing the required thickness of the glass 144. Also, as the Verdet constant is wavelength dependent the system can be switched from fluorescence to reflection.

The variation in magnetic field strength required to carry

out these functions can be achieved by varying the electrical current in a wire coil wound around the glass cylinder 144 or by sliding the magnetic cylinder 146 in an axial direction so that a greater or lesser magnetic field interaction length with the active glass medium 144 can be effected. The Verdet constant is generally greater for short wavelengths and as the dependence curve shapes vary for different materials it is possible using suitable combinations to arrange a maximum rotation for the blue excitation wavelength and a compressed range of rotation for the fluorescence. This will result in the most efficient use of light.

In another preferred embodiment of the present invention, the beamplitter of the endoscope includes phase plates (or retardation elements): optical elements of a material with a physical structure that is anisotropic at a molecular or crystalline level. In classical optical terms, the spring stiffness of the mechanical oscillators in the two orthogonal polarisation states is different because of the differing bond types or degree of strain within bonds in the two directions. This means that the velocity of propagation of electromagnetic vibration in the visible region differs for the two orthogonal polarisation vector directions, the material is said to be birefringent, that is, having two Indices of Refraction. The two directions of the crystal plate are called the fast axis and the slow axis. (The two sets of electromagnetic propagation direction are sometimes called the ordinary and extraordinary) - o and e rays. (Note the E vector used previously stands for electric field vector).

Birefringent prisms are commonly made from uniaxial crystals (e.g. calcite) and their use to separate light beams of orthogonal polarisation state has been described above.

A phase plate is effectively a 'parallel sided prism' of a birefringent material. If light impinges at right angles to the waveplate surface there is no deviation between the e and o ray, but waves with the E vector parallel to the slow axis are retarded relative to waves with the E vector parallel to the fast axis. A plane polarised wave entering the plate at an intermediate angle between the slow and the fast axes is resolved vectorially into two orthogonal polarisation states which propagate at different velocities (and with different wavelengths, their frequency being constant). The two waves leave the waveplate with relative phase shift. The polarisation state of the light when it leaves the wave plate is determined by the phase angle.

Anisotropy and phase shifting can also be induced and tuned in isotropic materials by straining the interatomic bonds either with a mechanically applied force, (stress induced birefringence) or by the application of a voltage between plates which produces and electrical field (the optical Kerr effect) and these principles could also be applied to a tuneable beamsplitter for confocal use.

In another embodiment of the present invention, liquid crystal systems are employed to rotate light within the endoscope head optically. Liquid crystals can be optically active, birefringent, or both, so their principles of operation is covered in the two previous embodiments. The rotatory power of cholesteric liquid crystals is very large of the order of 40,000° per mm compared with ~1° per mm for corn syrup and 21.7° per mm for quartz. The major advantage of using liquid crystal systems, therefore, is the compactness possible, and their being electrical controllable and tuneable. Liquid crystal display screens use nematic liquid crystals and these are commercially available made up as electrically controllable variable phase retarders. A supertwisted nematic liquid crystal

'valve' could be used as an electrically controllable tuning device for reflection confocal microscopy. It would also have enough rotation in the 'power off' mode to give colour separation for fluorescence imaging.

In another preferred embodiment of the present invention, the intrinsic polarisation properties of the reflecting object (or of the intermediate optical medium) is used to obtain optical rotation between excitatory and return light, as many biological materials exhibit birefringent properties and/or produce optical rotation.

Modifications within the spirit and scope of the invention may readily be effected by person skilled in the art. It is to be understood, therefore, that this invention is not limited to the particular embodiments described by way of example hereinabove.

DATED THIS 27TH DAY OF AUGUST 1998
OPTISCAN PTY LTD
By its Patent Attorneys
GRIFFITH HACK
Fellows Institute of Patent
Attorneys of Australia

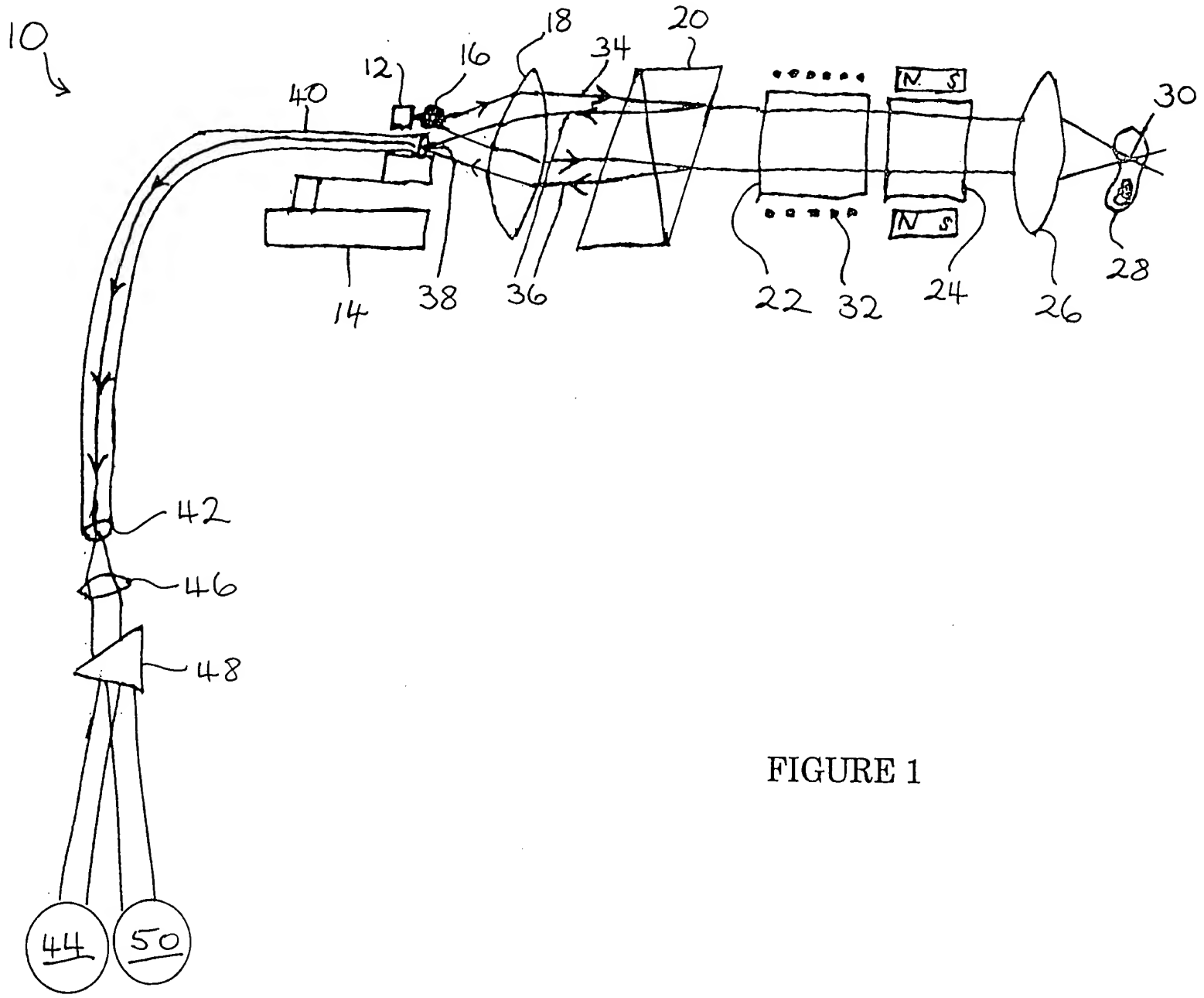

FIGURE 1

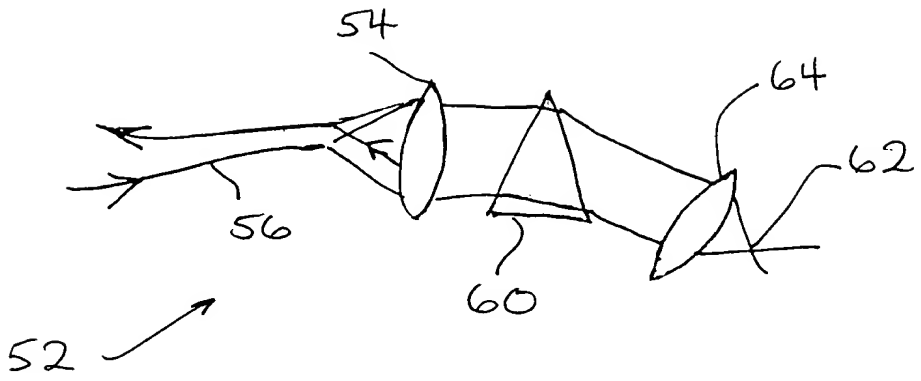

FIGURE 2

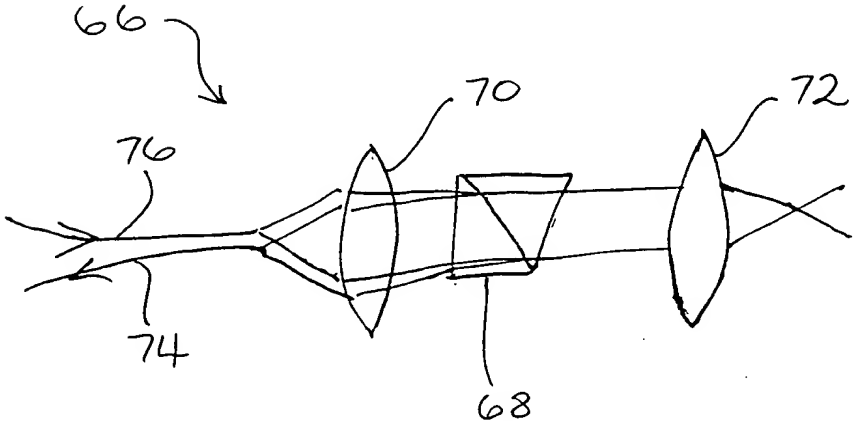

FIGURE 3

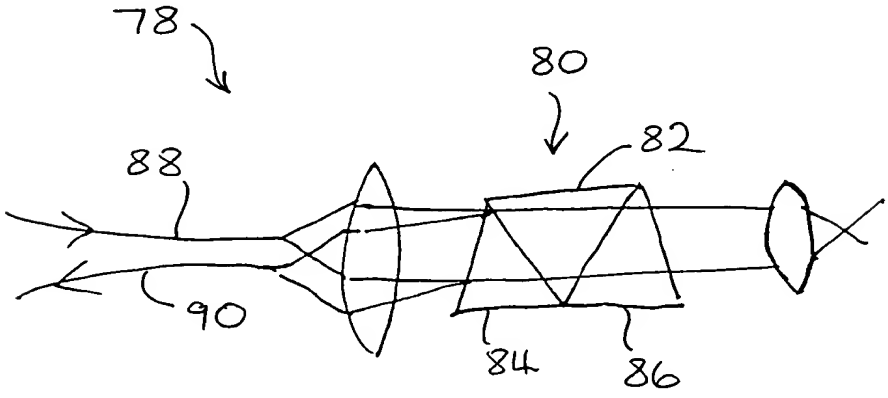

FIGURE 4

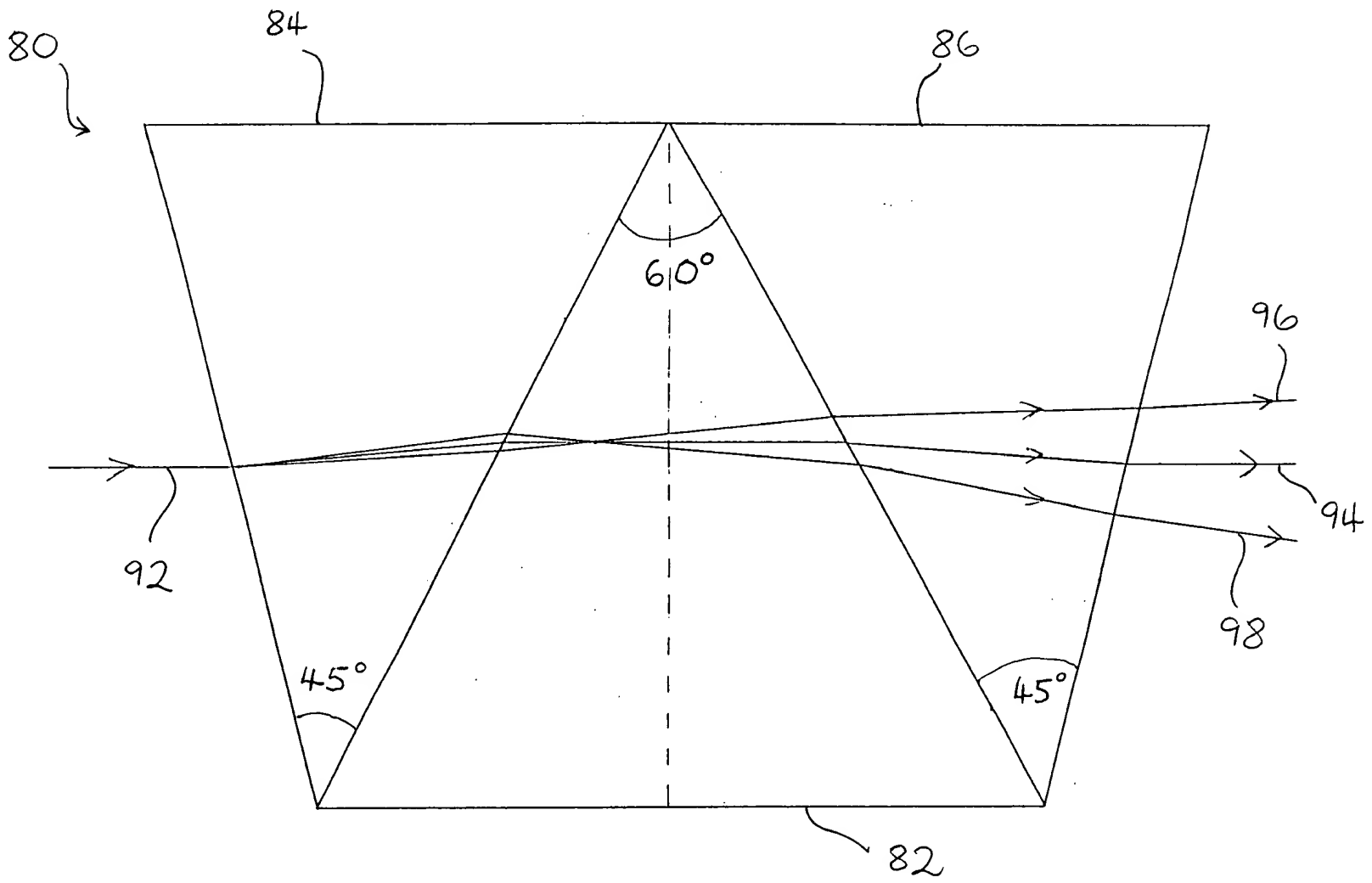

FIGURE 5

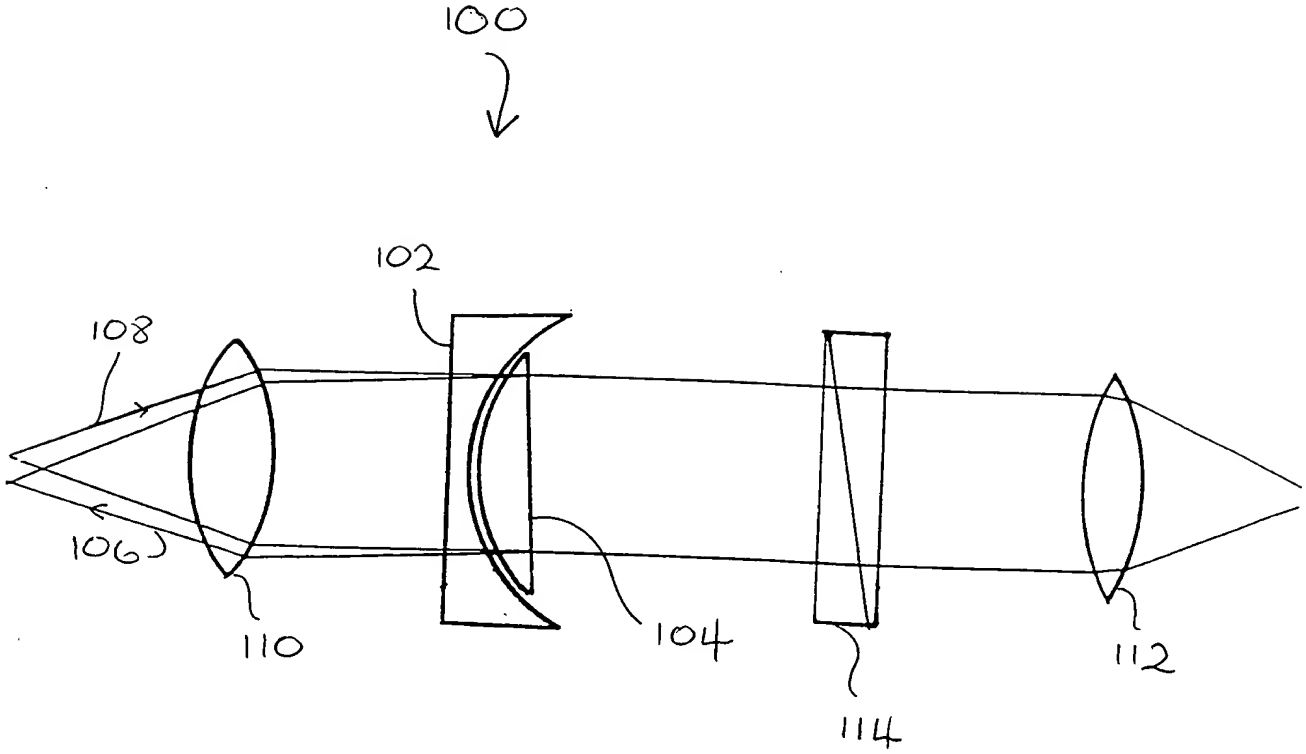

FIGURE 6

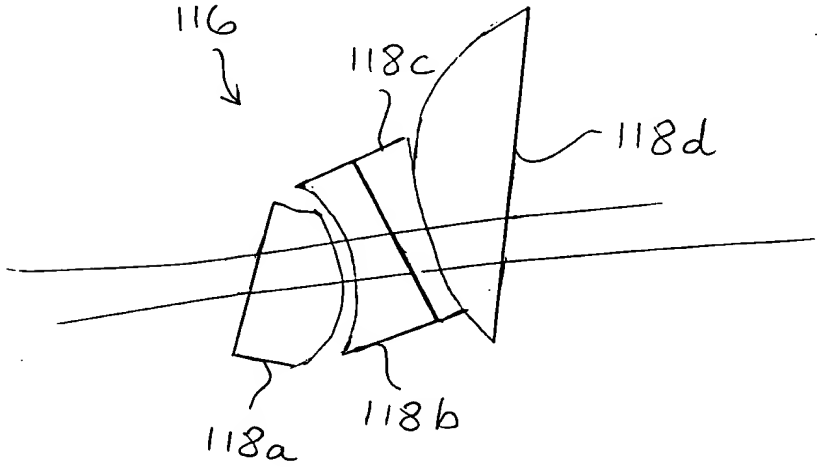

FIGURE 7

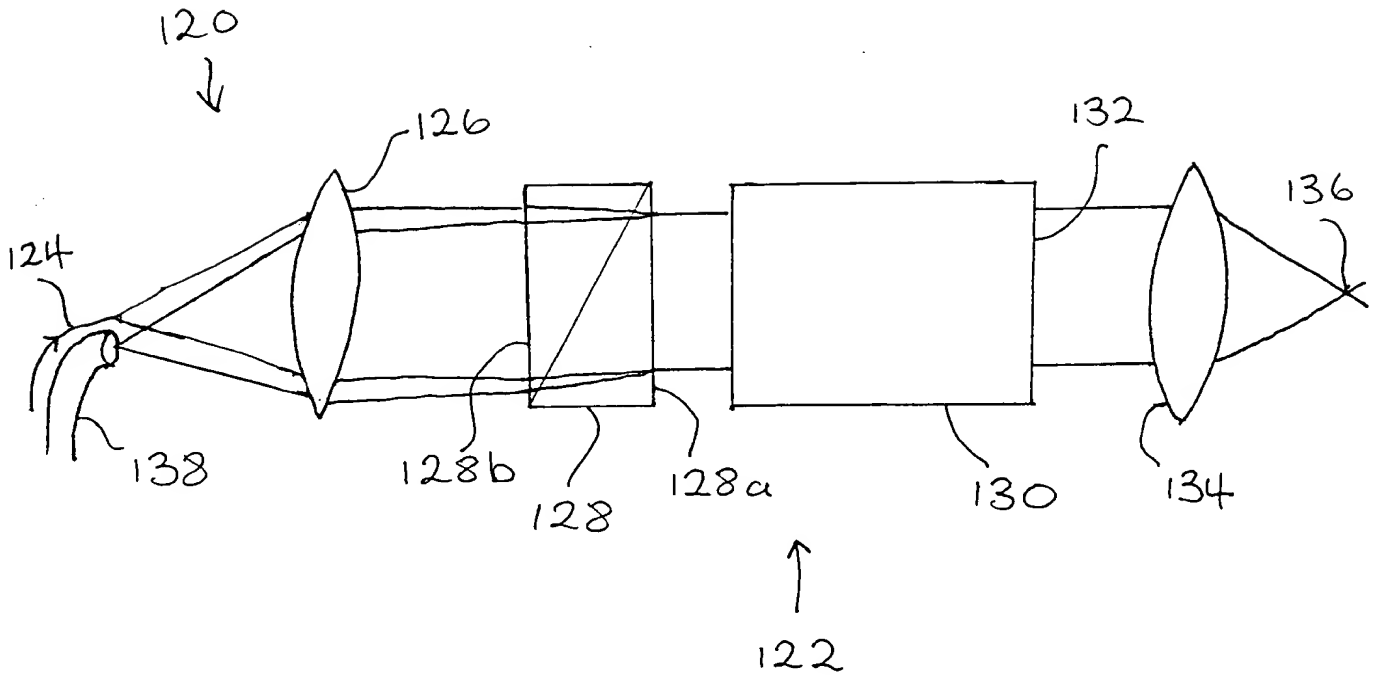

FIGURE 8

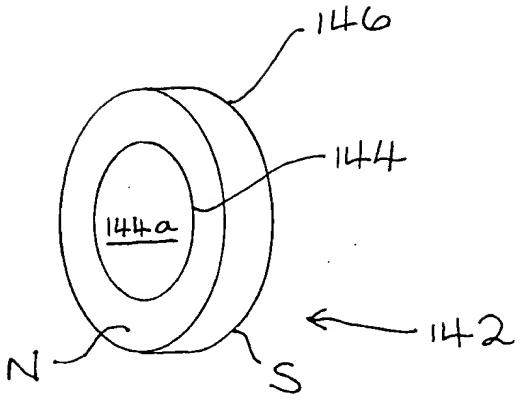

FIGURE 9